ECONOMIC OPERATION OF POWER SYSTEMS

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Connected load

It is defined as the sum of ratings of all electrical equipments that are connected at the supply point regardless of their status of operation

It is calculated depending on the installed equipment without measuring or testing their actual demand

The connected load, which is independent of time, is greater than the maximum load demand

Maximum demand

it is not obligatory that the maximum demand is equal to the connected load

It is calculated in a certain time interval by measuring the greatest load demand during this time interval

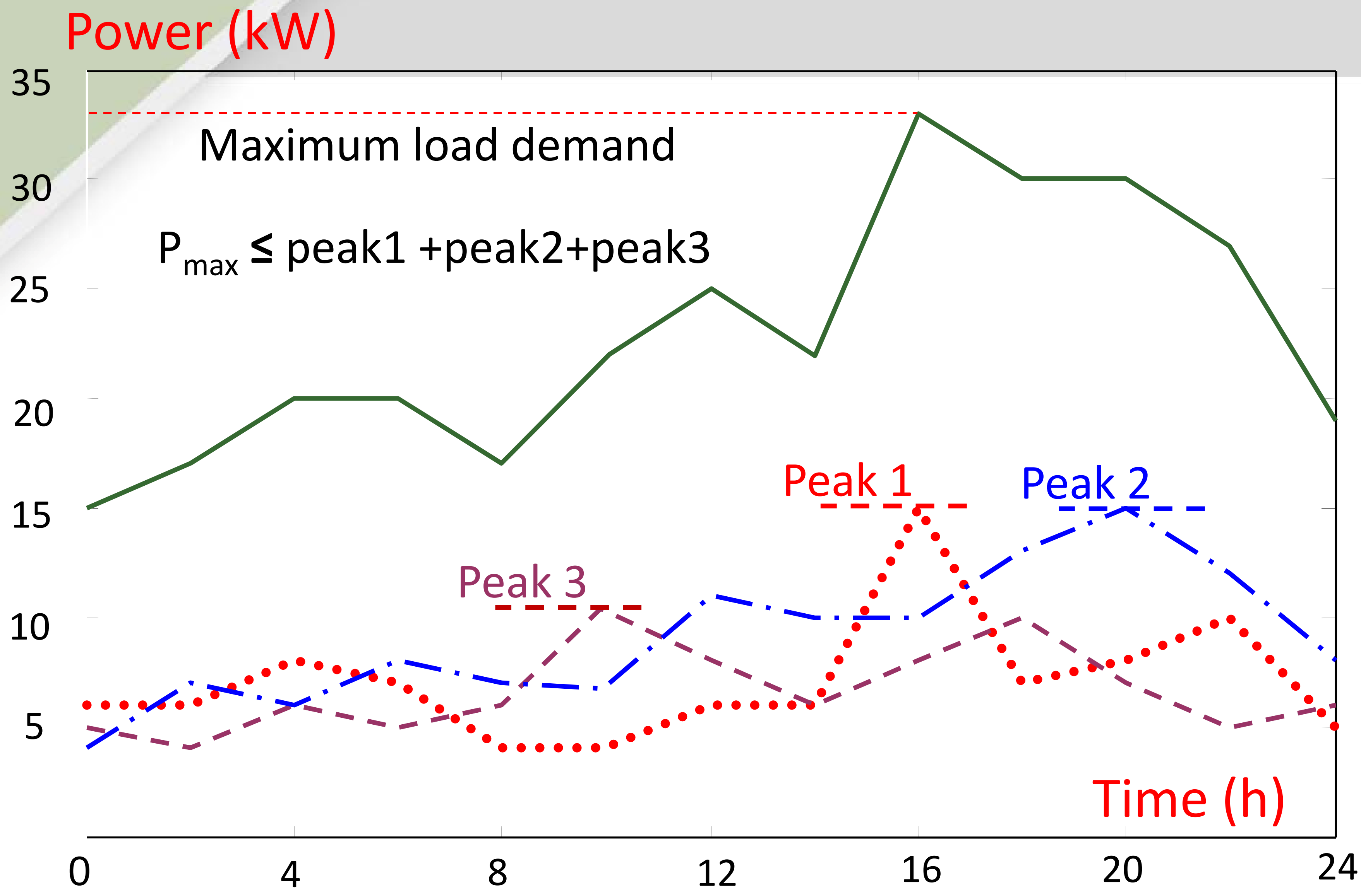
The reason is that the connected loads are switched on and off regularly

Even for the loads that are switched on, they are not properly operating with their full ratings

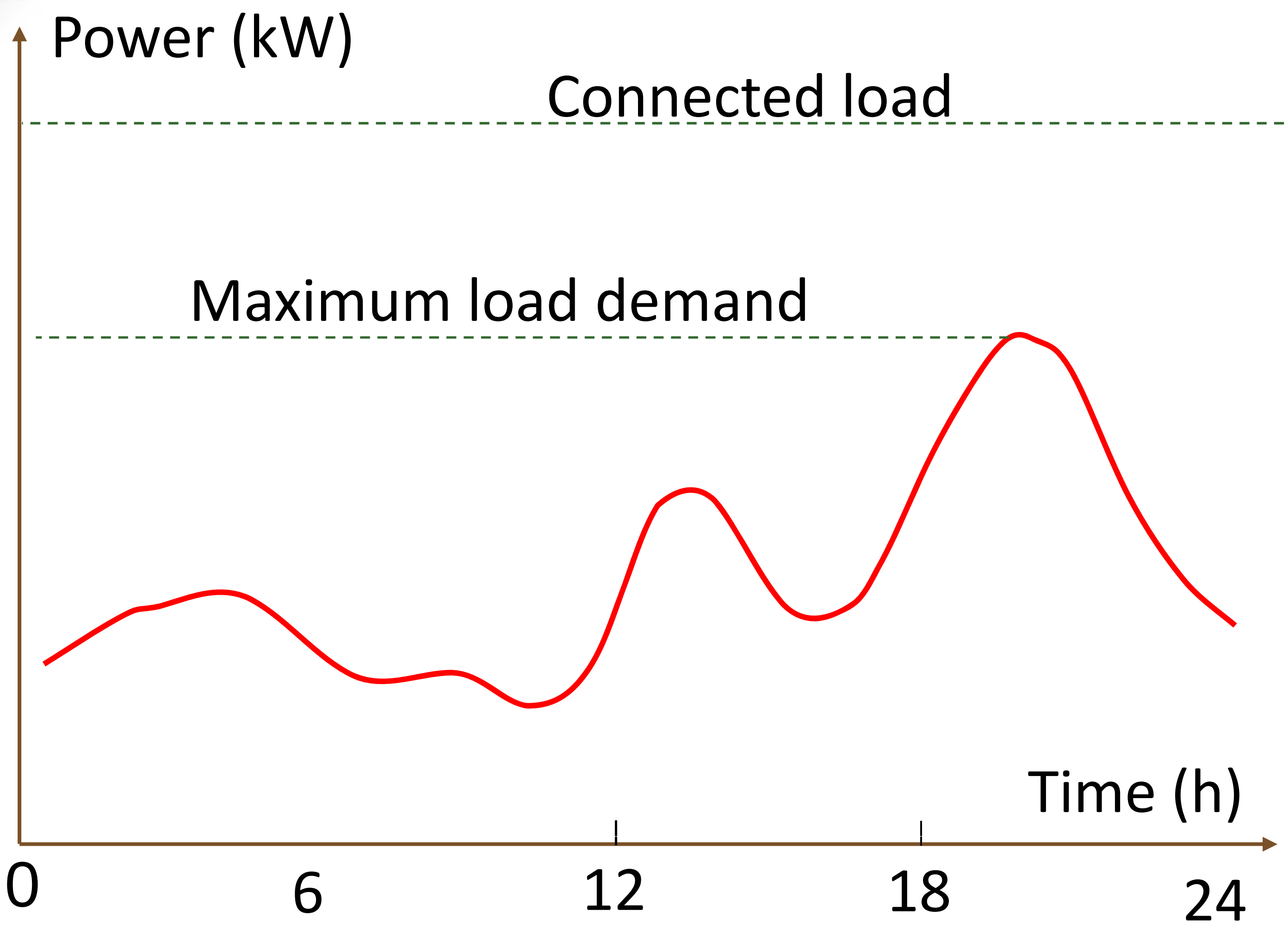
Maximum demand

The maximum load demand <u>can not</u> be calculated simply by adding the <u>maximum demands of individual loads</u> since the individual maximum demands occur at deferent times

Maximum demand



Connected load



Average Load

The average demand or average load is defined as the total energy delivered in a certain period divided by the time interval

It is possible to calculate a daily average load, weekly average load, monthly average load and yearly (annual) average load

Average Load

$$\text{Daily average load} = \frac{\text{total energy(kWh) supplied in one day}}{24\ \text{(h)}}$$

$$\text{Weekly average load} = \frac{\text{total energy(kWh) supplied in one week}}{24 * 7\ \text{(h)}}$$

$$\text{Monthly average load} = \frac{\text{total energy(kWh) supplied in one month}}{24 * 30\ \text{(h)}}$$

$$\text{Annual average load} = \frac{\text{total energy(kWh) supplied in one year}}{24 * 365\ \text{(h)}}$$

Installed capacity

The installed capacity is the sum of the ratings of all stations available to supply the system

Operating factors

Some factors are developed from operating curves to give useful indications about the cost issues of power systems

Demand factor

The ratio between the real maximum load demand on the system and the connected load

$$\text{Demand factor} = \frac{\text{maximum demand}}{\textit{connected}\ \text{load}}$$

The demand factor varies from time to time and its value is always *<u>less than or equal to unity</u>*

The connected load is always known and thus, it will be easy to calculate the maximum demand if the demand factor for a certain supply is known at different time intervals and seasons

Typical values of the demand factors

Load type	Capacity	Demand factor
Residential loads	< 0.25 kW	1.0
	< 0.5 kW	0.6
	> 1 kW	0.5
Commercial loads	Office and restaurant	0.7
	Theatre and small industry	0.6
	School	0.55
	Hotel	0.5
General power service	< 10 Hp	0.75
	10-20 Hp	0.65
	20-100 Hp	0.55
	> 100 Hp	0.5

Load factor

The ratio between the average load demand and the maximum demand during a certain period

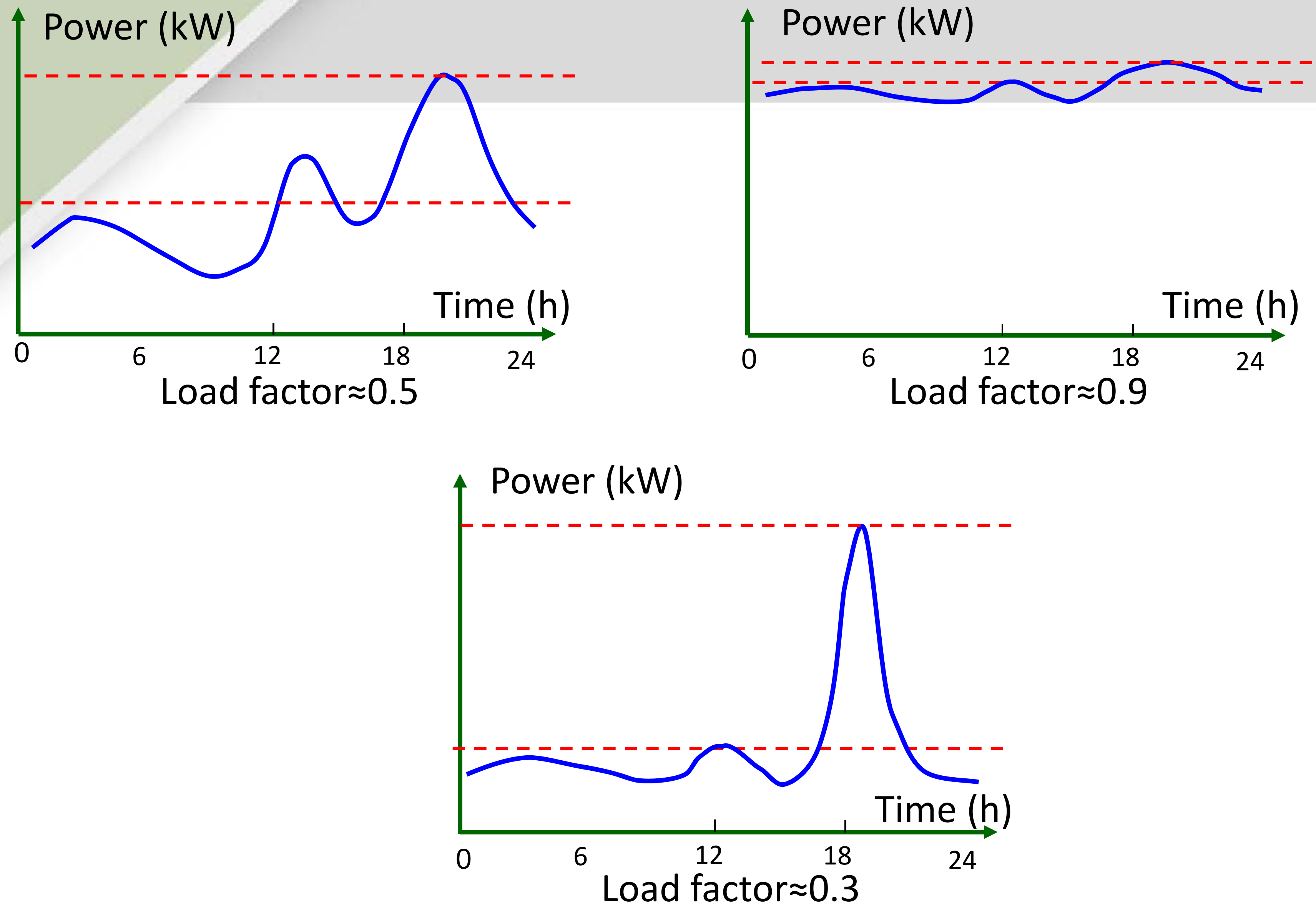
$$\text{Load factor} = \frac{\text{average demand}}{\text{maximum demand}}$$

- The magnitude of the load factor is *always less than or equal unity*
- For almost constant loads, the load factor is close to unity
- With strongly varied loads, it is close to zero

Standard load factors

Load type	Load factor
Residential loads	*10-15%*
Commercial loads	*25-30%*
Industrial loads:	
Less than 25 kW	*30-50%*
100-500 kW	*60%*
> 500 kW	*80%*

Load factor for three load profiles



Diversity factor

The maximum demands of individual loads do not take place at the same moment

The sum of individual peaks is not used as a measure of the maximum load demand

The maximum installed power is usually less than the sum of individual maximum demands

The diversity factor is *greater than or equal unity*

The ratio of sum of individual maximum demands of all customers to the maximum demand for a specific station is known as the diversity factor

Diversity factor

$$\text{Div. factor} = \frac{\text{sum of individual maximum demands}}{\text{maximum demand of power station}}$$

diversity factor for different load types

Elements of system	Res. loads	Com. loads	Large users
Between consumer	*2.0*	*1.46*	-
Between transformers	*1.3*	*1.3*	*1.05*
Between feeders	*1.15*	*1.15*	*1.05*
Between substations	*1.1*	*1.1*	*1.14*
consumer to transformer	*2.0*	*1.46*	-
consumer to feeder	*2.6*	*1.9*	*1.15*
consumer to substation	*3.0*	*2.19*	*1.32*
consumer to generator	*3.29*	*2.41*	*1.45*

Capacity factor

The capacity factor takes into account the excess of the installed power of station more than the actual required demand

The excess of power is known as the *reserve power*, which takes into account the expected future expansion and unexpected sudden load increase

The capacity factor is defined as *the ratio of the average load supplied by a station to the rated (installed) capacity of this station*

The capacity factor is *less than or equal to unity*

Capacity factor

$$\text{Capacity factor} = \frac{\text{average demand}}{\text{rated capacity of power plant}}$$

Multiplying the average demand and the rated capacity by time, the capacity factor can be defined as the ratio between the actual energy produced and that would be produced if the plant were operated at its full capacity

$$capacity\ factor = \frac{\text{Annual energy(kWh)}}{\text{rated capacity* no. of operating hours}}$$

Utilization factor

The utilization factor represents a measure of the power utilization of power plants

It is less than unity

The utilization factor is defined as *the ratio between the maximum demand and the rated capacity of the power plant*

$$\text{Utilization factor} = \frac{\text{maximum load demand}}{\text{rated capacity of power plant}}$$

Reserve factor

The ratio between the rated capacity of a power plant and the maximum demand is known as the reserve factor plant

Typical value of the reserve factor is between 1.2 and 1.4

$$\text{Reserve factor} = \frac{1}{\text{utilization factor}}$$

$$\text{Res. factor} = \frac{\text{rated capacity of the power plant}}{\text{maximum load demand}}$$

Reserve power

The power system is continually subjected to unexpected load changes

The generating units supply about 85-90% of their capacity maintaining the remainder for emergencies

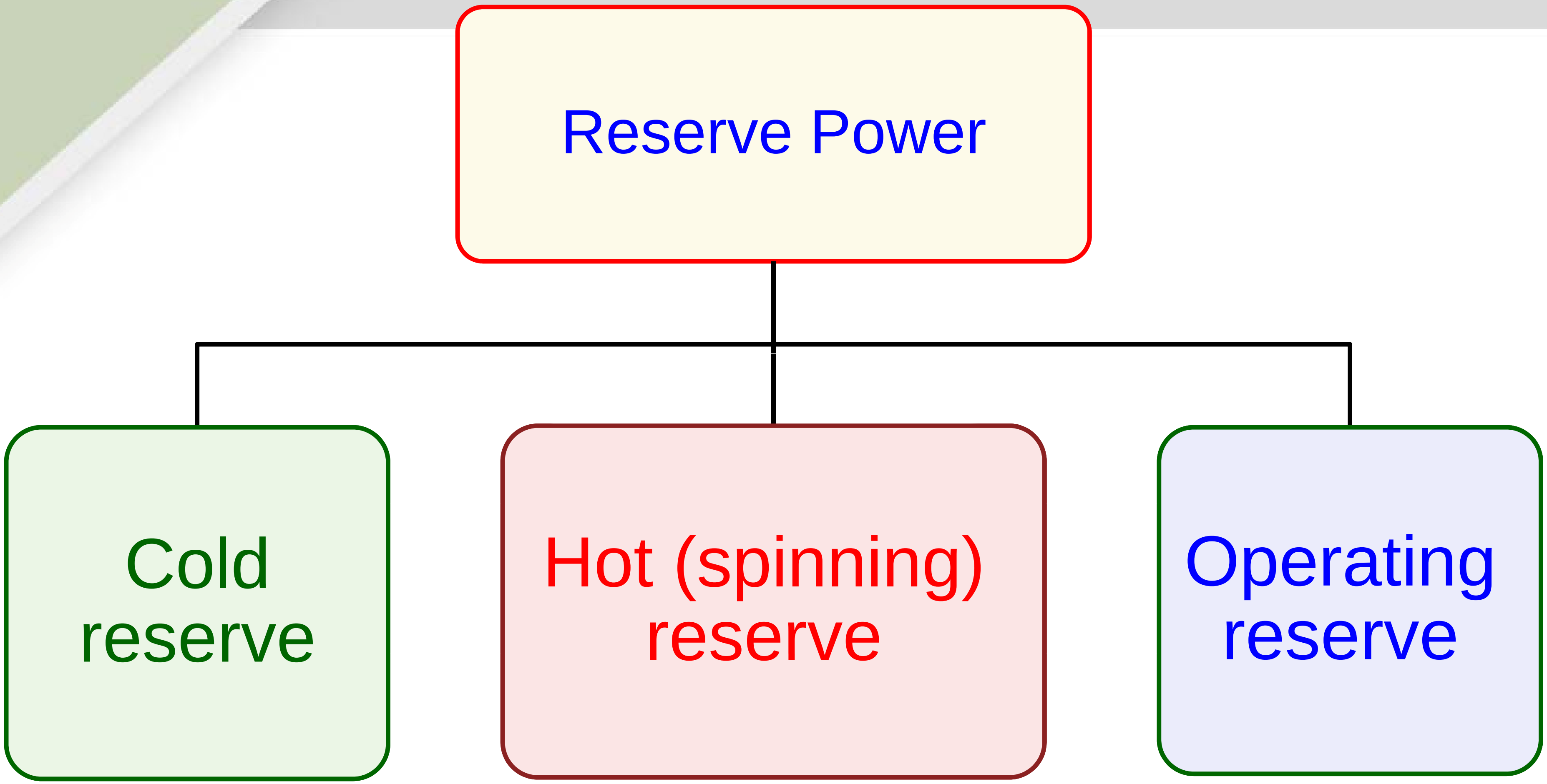
Some units are kept in the hot status to be connected to the network as fast as possible

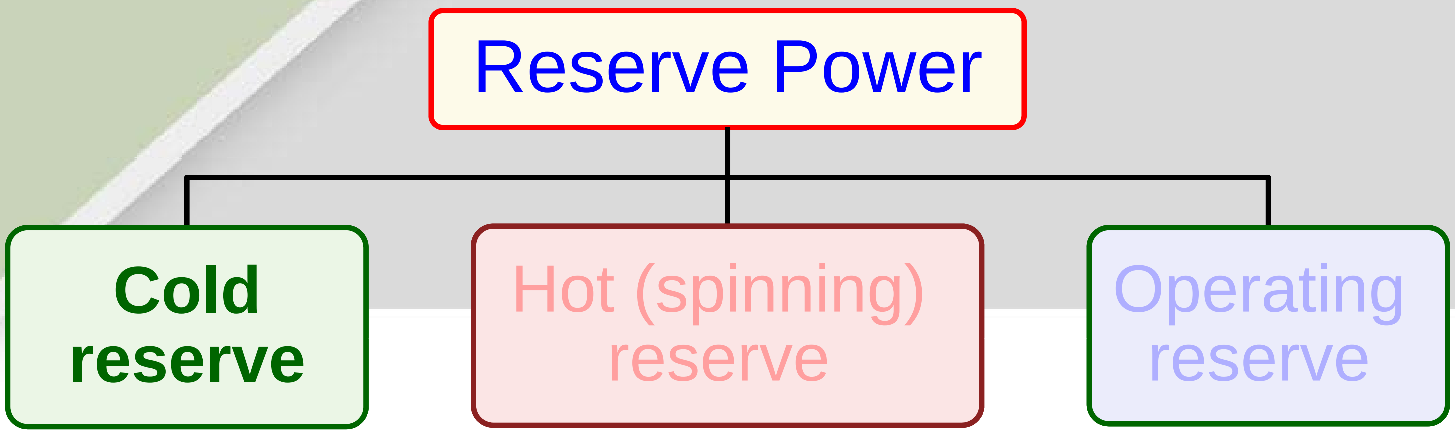
Reserve power

The need for reserve power arises due to some abnormal conditions in power system

- Sudden unexpected increase in the load demand
- Forced outage of generators or other equipments due to stability problems
- Underestimating the load demand due to some errors in the load forecasting
- Local shortage in the generated power (e.g. due to the outage of a transmission line)

Reserve power



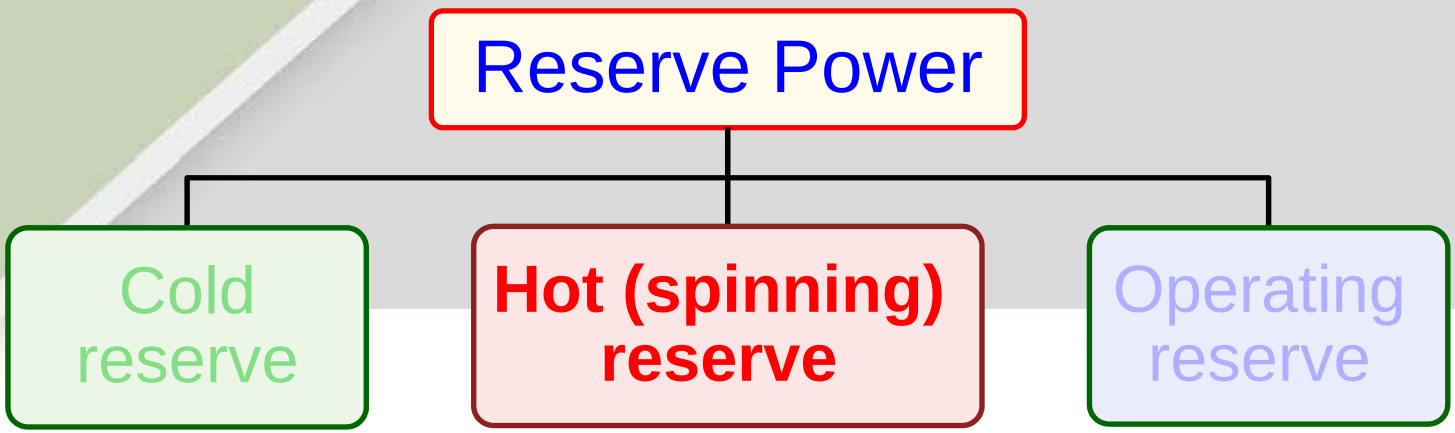


Cold reserve

Some units are kept or reserved for service but they are not available in the immediate loading

It is a portion of the total reserve power that is available for gradual utilization

The cold reserve power is the summation of the rating capacity of all generating units that are not in actual operation but ready to be loaded



Hot (spinning) reserve

The spinning reserve is defined as the extra amount of active power that boilers can provide immediately through governor action

The boilers have to be in the hot status with proper conditions (pressure and temperature)

The total spinning reserve has to be greater than the largest generating unit in the power system

Reserve power

The choice of the operating and standby unit as well as the distribution of reserve power on different power plants depends on the following factors:

The start up cost: depends on the start up time “the time interval between the order of starting to the moment where the unit delivers power to the network”

Units with high start up cost have not to be frequently switched on and off. Such units can provide hot reserve power but not cold reserve power.

Reserve power

The shut down cost: the cost due to the wasted energy during the shut down of the unit. It depends also on the type of the unit

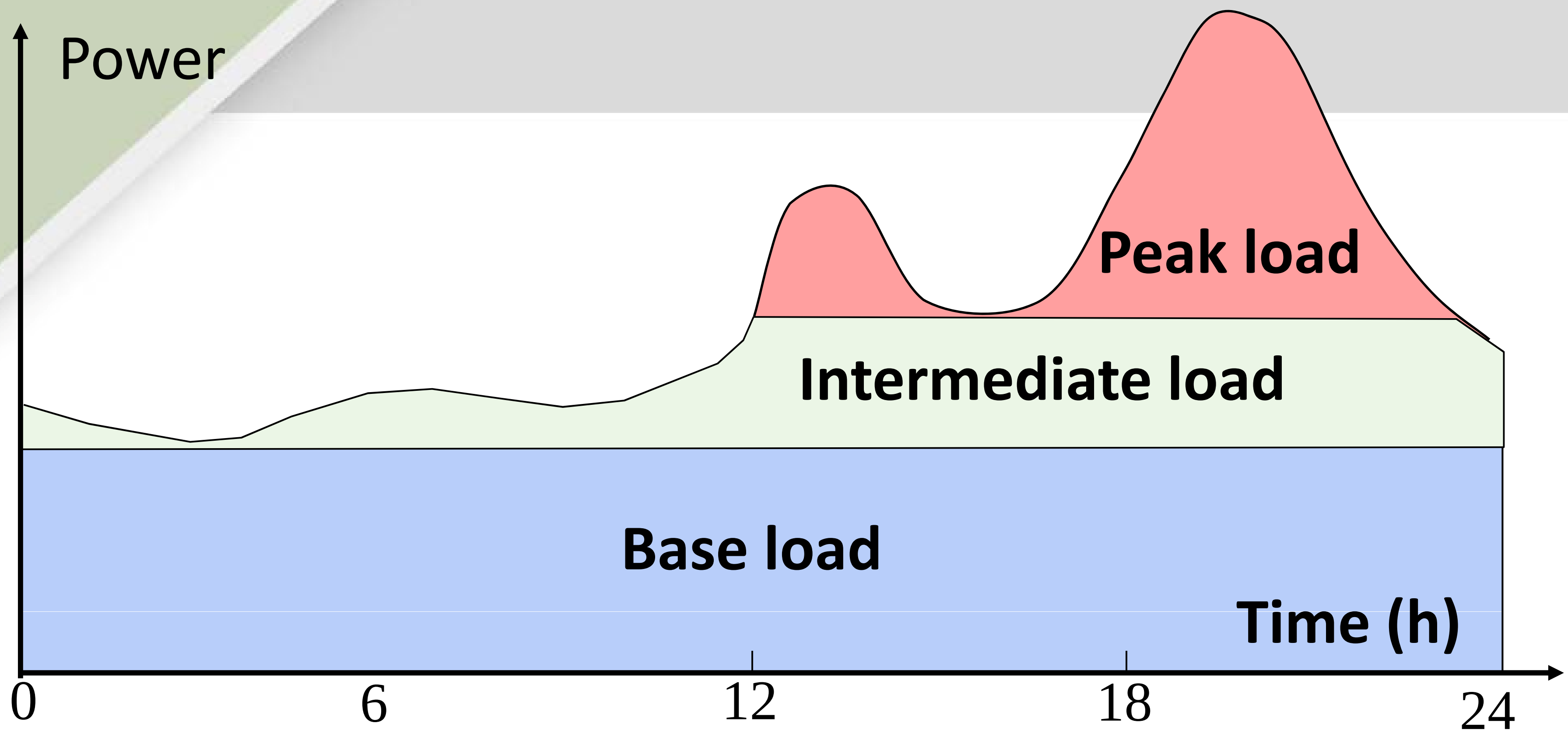
Ramp rate of the unit: *the increase of power that can be obtained from a generating unit in a specific time.* The power **can not** be increased or decreased suddenly but it needs a certain time per kW. This prevents the effective use of slow units (low ramp rate) for spinning reserve.

The total reserve power is not obtained from a single unit because this would take a long time. Rather, the spinning reserve is distributed over the available units to get the required power in a short time.

Base load and peak load

- In the case of using only one power plant, the capacity of the power generation will be defined according to the peak value
- The plant will operate at a part of load for prolonged time, which decreases the efficiency
- Several smaller units are installed with some of them covering base load and others covering peak load
- The units that cover the base load operate continuously, while those taking the peak load operate when required
- All units operate near their rated power with high efficiency

Base load and peak load



- base load has almost unvarying value
- intermediate load varies within certain limits
- peak load vary randomly

Base load and peak load

The generating units that operate as base power plants should have the following characteristics:

- Low operating cost since they operate continuously
- High capability of operating continuously for long time
- Low and fast maintenance requirements
- The load factor is very high and reaches unity for many units

Thermal, nuclear and hydraulic power plants are conventionally considered as base load plants

Base load and peak load

The units that operate as peak power plants should have the following characteristics:

- Very fast response to load variation (high ramp rate)
- Low start up time
- Low start up cost
- Low capital cost for economic operation since they operate for relatively short time during the year
- Constant voltage and frequency against the load fluctuations
- The load factor is very low in the range of 0.1-0.6

Steam, gas turbine and diesel power plants are used as peak power plants.